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IRON REMOVAL BY RAPID SAND FILTRATION[1]

By Frank E. Hale

Upon the Brooklyn watershed there are two mechanical filter plants originally designed to purify by alum treatment the waters of Baiseley's Pond and Springfield Pond. A few years ago the operation of both of these plants was changed to that of iron removal from well waters at these points. The following table (No. 1) shows the character of the water treated at the Baiseley plant together with its efficiency in iron removal:

TABLE 1

Baiseley's filter plant

		1912		1913	
		Raw water	Filtered water	Raw water	Filtered water
Chemical analysis, parts per million:					
Nitrogen as	Free ammonia	0.429	0.111	0.500	0.211
	Albuminoid ammonia	0.045	0.016	0.034	0.026
	Nitrite	0.002	0.025	0.012	0.009
	Nitrate	1.18	0.98	1.05	0.87
Chlorine		12.5	12.7	11.0	10.8
Total solids		162.	134.	160.	143.
Hardness		62.	66.	62.	70.
Alkalinity		37.	38.	41.	34.
Iron	Average	10.72	0.47	11.35	0.32
	Minimum	7.60	0.25	6.00	0.10
	Maximum	14.60	0.75	26.00	1.00
Biological examination:					
Bacteria per cubic centimeter		2	1	2	1
B. coli	0.1 cc	0%	0%	0%	0%
	1.0 cc	0%	0%	0%	4%
	10.0 cc	0%	0%	2%	9%
Microscopic organisms, units per cubic centimeter		0	0	0	0

It will be noted in the above analyses that there is a reduction not only in iron but in the nitrogen determinations and total solids.

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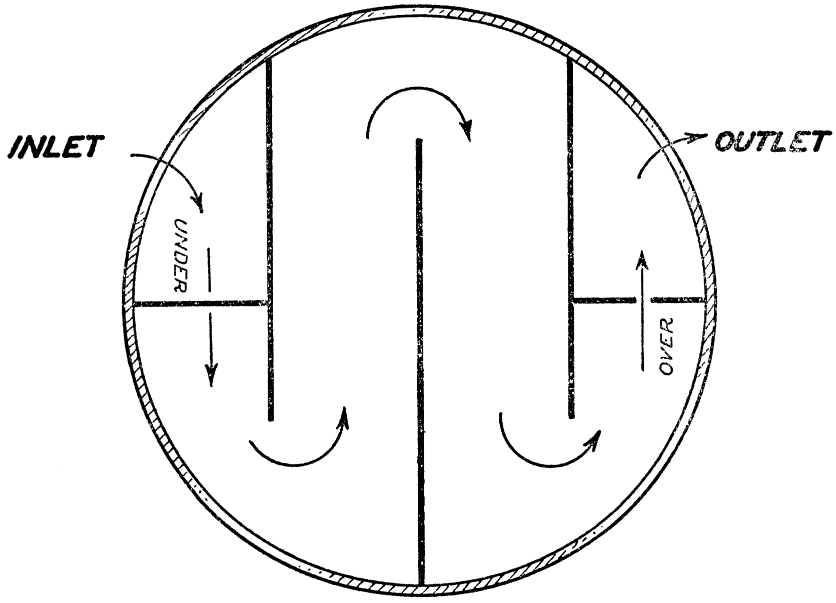
[1] Read at meeting of New York Section, December 15, 1915.

Without quoting analyses the results at the Springfield plant have been equally satisfactory although the character of the water is entirely different, being a mixture of two waters. The water is less hard, has considerably more chlorine and only a few parts of alkalinity.

It is not necessary to describe both plants but it may be well to give some details of the operation of the Baiseley plant. There are ten filter tanks 15 feet 3 inches in diameter, arranged in two rows, with two sedimentation tanks 18 feet in diameter, one for each row of filters. The sedimentation tanks are baffled as shown in diagram 1.

SEDIMENTATION BASIN, BAISELEY'S FILTER PLANT



The water is pumped and boils up into the inlet chamber, passes *under* the first baffle, back and forth around the center baffles and *over* the last baffle into the outlet chamber. The only aeration is due to a leakage of air in the well system to the extent of about 5 per cent by volume, and absorption of oxygen from the air during sedimentation and filtration. The water passes the sedimentation tanks in about thirty-five minutes. It enters the filters through baffle chambers at the bottom, rises to the top of the sand beds and passes down through 2 feet of sand, 6 inches of fine gravel and 6 inches of coarse gravel to the strainer system. The filters operate at about 100,000,000 gallons per acre per day.

The sand originally in the filters had an effective size of about 0.37 mm. but had become coarsened by removal of fine sand during washing to about 0.48 mm. when the plant was started for iron removal March 21, 1912. During the first year of operation the sand changed still further to an effective size of 0.65 mm. with a uniformity coefficient of about 1.6. The depth of sand decreased from 30 inches to 18 to 28 inches in different filters.

The sand is washed by reversed flow of filtered water, together with agitation by compressed air, and assisted by raking or paddling by hand. Wash water amounted to about 5 per cent of the yield in July, 1913, and is about 2 per cent now; rate of washing 725 gallons per minute for thirteen minutes. The period of run, at first forty hours, was soon shortened to twenty-four hours, was about sixteen hours in a year's time and now is about fifteen hours. The filters are washed at 8-foot loss of head.

The sand becomes coated with iron oxide and thus ripens, this oxide acting to oxidize the iron in the water probably according to the equation:

$$FeCO_3.H_2CO_3 + Fe_2O_3 + H_2O = Fe_3O_4 + 2\ H_2CO_3$$

The sand filters thus become not only filters but oxidizing contact beds. At the start the iron was not efficiently removed but improved rapidly as the sand ripened. In four months after operation started the iron was down to about 0.5 p.p.m.

In the summer of 1914, the department of health ordered the Queens County Water Company to shut down their station at Rockaway Park owing to high iron content and resulting complaints from consumers. As the water was needed, the Department of Water Supply, Gas and Electricity coöperated with the water company in designing a rapid sand filter in accordance with the experience at Baiseley and Springfield Stations. Owing to the necessity for rapid construction certain difficulties were encountered, and the studies made to bring this plant to a high state of efficiency seemed worthy of record. The first conference was held July 31, 1914. Construction was started August 3, one filter completed August 18, the second completed August 19, and both put into service August 21, there being thirteen working days with two days' loss on account of weather.

The morning after the conference a sample of the water to be treated was brought to Mount Prospect Laboratory for experiment. Table 2 shows the analysis and results of experiments made to remove the iron:

TABLE 2

Analysis of well water—Rockaway Park Station

	p.p.m.
Free carbonic acid (CO_2)	31.2
Iron (Fe)	11.20
Hardness ($CaCO_3$)	47.
Alkalinity ($CaCO_3$)	32.
Chlorine (Cl)	64.0
Nitrate (N)	0.0

Laboratory experiments

	p.p.m.
Iron after aeration for one-half hour and filtered through paper	7.20
Iron after neutralization of carbonic acid with soda ash (Na_2CO_3) and filtration through paper	0.30
Iron after neutralization of carbonic acid with calcium hydrate (CaO_2H_2) and filtration through paper	0.10

The experiments indicated that if simple aeration did not sufficiently remove the iron the addition of either soda ash or milk of lime to take up the free and halfbound carbonic acid would render filtration effective. The plant was designed so that chemicals could be used. Aeration was accomplished by pumping the water vertically into the air, allowing it to splash into a trough and pour over a weir as it passed through a small sedimentation tank. The filters were built in duplicate, of heavy plank, in rectangular shape. The water came onto the sand from a central trough and the filters were arranged to wash by reversed flow into a central trough. The wash water passed to a hole dug in the sand.

Many samples of sand were analyzed, but owing to shortness of time the attempt was made to procure sand of right size on the spot by screening, since the first sample from the bank had an effective size of 0.51 mm. and a uniformity coefficient of 3.0. This was an unwise procedure. Table 3 gives results of analyses after the first season's run.

TABLE 3

Analyses of sand samples from filters after first season

SAMPLE NO.	DATE EXAMINED 1914	SOURCE	EFFECTIVE SIZE	UNIFORMITY COEFFICIENT
1618	October 13	Filter 1, top sand ½ inch–¾ inch thick	0.28	1.5
1619	October 13	Filter 1, just below top sand.........	0.84	2.2
1620	October 13	Filter 1, 1 foot depth..............	0.95	2.1
1621	October 13	Filter 1, bottom sand on screens.....	0.62	3.1
1622	October 13	Filter 2, top sand....................	0.27	1.5
1623	October 13	Filter 2, just below top sand........	0.48	2.1
1624	October 13	Filter 2, 6-inch depth..............	0.94	2.0

It will be noticed that the top sand was altogether too fine and the bulk of the sand too coarse.

During the first season several inspection trips were made to the plant and many experimental tests carried out. Table 4 gives the results obtained on September 16, 1914:

TABLE 4

Experimental tests during inspection made September 16, 1915, Rockaway Park

HOUR	SAMPLE	RATE OF FILTRATION		SODA USED PER DAY	CARBONIC ACID CO_2	IRON Fe
		Gallons per minute	m. g. a. d.			
				lbs.	*p. p. m.*	*p. p. m.*
8.45 a.m.	Raw water.......	325	57	700		12.0
8.45 a.m.	Filtered water...	325	57	700		0.3
11.20 a.m.	Filtered water...	640	112	700		1.7
12.40 p.m.	Filtered water...	600	105	0*		1.4
1.30 p.m.	Filtered water...	600	105	0	22.0	3.4
1.40 p.m.	Filtered water...	380	66	0		2.5
2.30 p.m.	Filtered water ..	380	66	0	27.0	3.0
3.00 p.m.	Filtered water...	380	66	0	28.0	2.2

* Stopped 30 minutes previous.

During the early part of the season soda ash was used to neutralize the free carbonic acid, but the removal of iron was not satisfactory, there being nearly 2 p.p.m. of iron left in the filtered water when running at the rate of 112,000,000 gallons per acre per day, at which rate the plant should have run efficiently in order to equal the results obtained at the city's filter plants. It will be noted in the table that when running at 57,000,000 gallons per acre per day, the iron in the filtered water was only 0.3 p.p.m. but at the higher rate was 1.7 p.p.m.

The floc produced by soda ash is very fine and somewhat colloidal in character, and as the city's plants obtained perfect results without the use of any coagulant, it was believed that this was a useless expense and that the plant would work as well, if not better, without the soda ash, although the latter apparently precipitates the iron quicker. Maintaining the high rate, the soda ash was cut out and the analysis made at 12.40 p.m. showed as good results. The results were not quite as good an hour later, the iron having increased to 3.4 p.p.m. The rate was then lowered again, the use of soda ash still being discontinued, but the iron in the filtered water did not materially improve, ranging from 2 to 3 p.p.m.

TABLE 5

Filtration without soda at Rockaway Park—October 2, 1914

SAMPLE	TIME	RATE OF FILTRATION	CARBONIC ACID* CO_2	IRON* Fe
		m. g. a. d.	*p. p. m.*	*p. p. m.*
Raw water	3.45 p.m.	72.5	40	10.4
Filtered water	9.45 a.m.	61.5	12	1.0
Filtered water	10.15 a.m.	67.0		1.6
Filtered water	10.45 a.m.	72.5	23	2.3
Filtered water	11.15 a.m.	72.5		2.1
Filtered water	11.45 a.m.	61.5	26	2.6
Filtered water	12.15 p.m.	72.5		1.8
Filtered water	12.45 p.m.	61.5	28	2.3
Filtered water	1.15 p.m.	72.5		1.7
Filtered water	1.45 p.m.	72.5		1.7
Filtered water	2.15 p.m.	78.5		2.3
Filtered water	2.45 p.m.	84.5	28	2.7
Filtered water	3.15 p.m.	72.5	27	2.8
Filtered water	3.45 p.m.	72.5	26	2.3

* Analyses made at Mount Prospect Laboratory.

Owing to the city's experience, however, the plant was continued in operation without the use of soda ash. Table 5 shows the results of analyses made upon samples taken every half hour during a run at a moderate rate of filtration. The iron in the filtered water ranged from 1 to 2.8 p.p.m.

The results for the first season could hardly be called satisfactory, and it was believed that several changes in the plant were necessary for the second season's operation. A larger sedimentation tank was constructed 28 feet long, 21 feet wide and 12 feet deep. This tank was divided with baffles into seven compartments so that the water alternately moved rapidly downward and then slowly upward in order by changing rates of movement to obtain maximum sedimentation. However, it will be noted that comparatively little iron is removed by sedimentation, the process merely giving time for reaction and absorption of oxygen from the air.

The sand was also considered to be at fault and samples were obtained from firms in Massachusetts and New Jersey. The sand in the filter bed was replaced entirely with purchased sand, the bottom third receiving sand with an effective size of about 0.80 mm. and a uniformity coefficient of 1.65 and the upper two-thirds receiving sand with an effective size of 0.47 mm. and a uniformity coefficient of 1.40.

In order to have the plant ready for efficient service, experiments were started early and tests were made during an inspection trip on June 25, 1915, at the plant. The results of these tests are given in Table 6.

There were two periods of aeration and samples were taken before and after each and from each compartment of the sedimentation basin, also from the old sedimentation basin and aerator and from the filter bed with the filter running at about 50,000,000 gallons per acre per day. It will be noticed that about 4 p.p.m. of iron was removed by the aerators and about 4 p.p.m. by the sedimentation basin and about 7 p.p.m. by the filter beds. The filtered water still contained about 2 p.p.m.

The rate was then increased to about 125,000,000 gallons per acre per day. The aerators again removed about 4 p.p.m. of iron, the sedimentation basins, however, practically nothing, but the filters about 9 p.p.m., so that in the total effect the filters were nearly as effective at the high rate as at the low rate, but the water in neither case had opportunity to absorb sufficient oxygen to completely oxidize the iron, at least the oxidation was incomplete. It was advised that more aerators be installed so as to increase the number of splashes so arranged as to cause foaming of the water and trapping of air bubbles and giving the fullest opportunity for absorption of oxygen. The splashing is essential in order to get rid of the excess carbonic acid which is set free as fast as the iron oxidizes. The lack of oxidation was prettily demonstrated to the eye by the appearance of the water in the large sedimentation basin when operating at the 125,000,000 gallons per acre per day rate. The reddish color of the water, due to hydrate of Fe_2O_3, present during the lower rate changed to a green color, due to hydrate of Fe_3O_4, even in the last compartment, indicating insufficient oxidation.

TABLE 6

Experimental tests during inspection made June 25, 1915, Rockaway Park
Rate of filtration about 50,000,000 gallons per acre per day

SAMPLE	CARBONIC ACID CO_2	IRON FE
	p. p. m.	*p. p. m.*
Raw water	40	17.0
After first aeration	36	18.4
After second aeration	36	16.0
Second compartment sedimentation basin	34	13.2
Third compartment sedimentation basin	36	13.0
Fourth compartment sedimentation basin	33	12.0
Fifth compartment sedimentation basin	39	12.0
Sixth compartment sedimentation basin	36	12.0
Seventh compartment sedimentation basin	36	11.0
Effluent, large sedimentation basin	38	11.0
Effluent, small sedimentation basin and aerator	30	9.0
Effluent filter beds	20	2.2

Rate of filtration about 125,000,000 gallons per acre per day

SAMPLE	CARBONIC ACID CO_2	IRON FE
Raw water	46	16.0
After first aeration	46	13.6
After second aeration	42	14.4
Second compartment sedimentation basin	38	12.0
Effluent, large sedimentation basin	36	12.4
Effluent, small sedimentation basin and aerator	36	12.4
Effluent filter beds	24	3.6
Standpipe	12	1.6
Mixed Rockaway Park supply	14	0.6

A series of cascades was arranged so that the water splashed and foamed nine times before entering the large sedimentation tank. This remedied the trouble completely as shown from the samples taken July 19, 1915, from the plant in regular operation, the filter effluent showing only 0.20 p.p.m. iron. These results are shown in Table 7.

TABLE 7

Tests of plant in regular operation with additional aerators, July 19, 1915
76,000,000 gallons per acre per day

	IRON	HARDNESS	CL.	NITRATE
	p. p. m.	*p. p. m.*	*p. p. m.*	*p. p. m.*
Second compartment sedimentation tank......	7.00			
Effluent, small sedimentation tank............	8.80			
Filter effluent................................	0.20	29	44.8	0.00
Standpipe (outlet pipe)......................	0.30	26	44.0	0.05
Tap Fifth Avenue 4000 feet west of filter......	0.40	20	44.0	0.10

An inspection trip was made August 17, 1915, and tests carried out, samples being taken from the raw water, from the water after aeration, from the water after sedimentation as it goes onto the filters and from the effluent of the filters. The plant was operated at two rates, 69,000,000 gallons per acre per day and 114,000,000 gallons per acre per day and the iron in the effluent from the filters at both rates was only 0.05 p.p.m. This result could not be improved upon. The results of these tests will be found in Table 8:

TABLE 8

Tests during inspection made August 17, 1915, Rockaway Park

	RATE OF FILTRATION			
	350 gallons per minute (69 m. g. a. d.)		650 gallons per minute (114 m. g. a. d.)	
	Free CO_2	Fe	Free CO_2	Fe
	p. p. m.	*p. p. m.*	*p. p. m.*	*p. p. m.*
Raw water...........................	55	5.0	49	5.4
After nine aerators..................	41	5.0	40	5.4
After eleven aerators and sedimentation tanks (water to filter).........	31	3.5	31	4.2
Effluent from filters..................	19	0.05	22	0.05

The removal of carbonic acid is also obvious in the above table, the more so when one considers that the oxidation of iron continually increases the free carbonic acid. This removal accompanies and materially hastens the absorption of oxygen by the iron.

Table 9 gives the complete chemical analysis of the water as it comes from the filter plant.

TABLE 9

Analysis of filtered water July 19, 1915, Queens County Water Company, Rockaway Park, L. I.

	p.p.m.
Turbidity	0
Color	2
Odor	0
Albuminoid ammonia	0.008
Free ammonia	0.060
Nitrite	0.001
Nitrate	0.00
Total solids	125
Chlorine	44.8
Hardness	29
Alkalinity	11
Iron	0.20

SUMMARY

Removal of iron by mechanical sand filters is very satisfactory, more than 20 p.p.m. being reduced to 0.10 p.p.m. or less, under proper operation. Rates of filtration are high, over 100,000,000 gallons per acre per day. Wash water is low and periods of run are long as compared with alum filtration.

The efficient removal of iron depends upon several factors:

Sufficient aeration, by suction of air, by splashing and foaming, by sedimentation tanks which give time for reaction, and by ripening of the sand by deposition of adhering iron oxide which probably acts catalytically as a carrier of oxygen.

Removal of carbonic acid, which is set free as the iron is oxidized. This is facilitated by splashing, and by contact with air during sedimentation and filtration.

Sand of the right effective size, about 0.50 to 0.60 mm. and as uniform as possible, preferably less than 1.8 uniformity coefficient.

The first stage of oxidation is to the hydrate or basic carbonate of Fe_3O_4 as shown by a green color. For complete removal of iron to the last traces this oxide must be fully oxidized to the hydrate of Fe_2O_3 as shown by a red color. The equation of complete oxidation by dissolved oxygen is as follows:

$$4\,FeCO_3 . H_2CO_3 + O_2 + 4\,H_2O = 2\,Fe_2O_3 + 8\,H_2CO_3$$

whence it follows that 1.4 p.p.m. of dissolved oxygen will oxidize 10 p.p.m. of iron. There is usually sufficient oxygen in the water to complete the oxidation of the iron. To cause the reaction to take place the chemical equilibrium must be disturbed, the carbonic acid being necessarily removed. This is really the most important part of the process. Splashing is the most effective and rapid method, exposure to air accomplishing it slowly. The correct size of sand fully ripened is also very important for the finishing process to complete the oxidation and adequately filter out the last traces of iron.

DISCUSSION

MR. R. E. MILLIGAN: The speaker understands that the experiments referred to were conducted by the city of New York at Rockaway Park, and that the general conclusion was that the iron removed by the filter was in a colloidal condition and that the iron deposited on the sand grains caused a further deposition when the applied iron came in contact with the iron already removed; also that it was shown that better results were achieved when no caustic soda or other alkali was used. Is this correct?

MR. FRANK E. HALE: Fully as good results were obtained by aeration alone as by the use of alkali. The precipitate caused by alkali tends to be colloidal and pass through the filters.

MR. R. E. MILLIGAN: How long has the plant been in operation?

MR. FRANK E. HALE: Two seasons, operating days only from June to August. The sand was changed at the beginning of the present season, because the sand used the first season was of improper quality.

MR. R. E. MILLIGAN: It would be interesting to know how long the bed was used before using alkali.

MR. FRANK E. HALE: No alkali was used this season, it was used only at the beginning of last season. The iron content was reduced from 17 or 18 to 2 p.p.m. last year, when using alkali, but was reduced to as low as 0.05 p.p.m. this season when no alkali was used.

Mr. Robert Spurr Weston: Will Mr. Hale please state whether he has ever found manganese or humic acid in any of the Long Island waters, which would interfere with the oxidation of the ground water containing iron?

Mr. Frank E. Hale: There is apparently no humic acid in any of the well waters. If there were there would be likely to be color and our well waters are colorless. Manganese is probably present in small amounts; we do not usually test for it. If present it should help the oxidation, as manganese in alkaline condition is a carrier of oxygen.

Mr. Robert Spurr Weston: The experience of Mr. Barbour at Lowell, Massachusetts, and Mr. Lounsbury at West Superior, Wisconsin, is of interest. There you cannot increase the oxygen above 50 per cent of saturation without affecting the deferrization process.

The question was asked to find out if any of the Long Island waters contain enough humic acid or manganese to interfere with the precipitation of the iron.

Mr. Frank E. Hale: This was an interesting study to the author, because at the two city plants there was no trouble in getting the iron out readily; while at Beasley's a certain amount of air leaks into the pump system, at Springfield this does not occur. There is no evidence of air leaking into it at all. The only chance for aeration is during sedimentation. When the Rockaway Park plant started it was, therefore, a surprise that we did not get good results at once. There were progressively put in larger sedimentation basins, then more aerators and then better sand, and the right effect was finally obtained. In the author's opinion the character of the sand affects the results seriously. Next season there will be a chance to leave the aerators going and cut out the sedimentation basin, and vice versa, in order to study the exact effect of each more closely with a ripened sand of proper character.

Mr. Robert Spurr Weston: Is there reason to suppose that the coagulation of the iron already oxidized is what happens rather than the oxidation? Does not the oxidation take place quite rapidly with the gathering of fine particles of hydrate into larger aggregations capable of being removed on the sand by a process which takes time. For example, take two waters, both of which contain a large percentage of oxygen, showing a different time reaction; is not the coagulation involved in this case; and was not coagulation largely accelerated by the contact of accumulated hydrate with the finely divided hydrate in the plants mentioned in the paper?

Mr. Frank E. Hale: The iron hydrate, whether considered on top of the sand or about the sand grains is a factor in the oxidation, because there is not complete oxidation until the sand has ripened and remains coated; it cannot be washed off. There is no doubt that the precipitated iron oxide, accumulated as schmutzdecke, will give up a portion of its oxygen; this is certainly the case in corrosion of iron pipe. But there is a certain balance between the carbonic acid and the iron in the water which has to be disturbed. It would probably be called mass action. If there is an excess of carbonic acid before the water reaches the air the iron does not oxidize even though there is an excess of dissolved oxygen. The ripening of the sand is an important factor in getting complete iron removal.

A Member: From the tables showing successful operation it would seem that most of the iron is removed on the filters and very little deposited in the settling basins. Will the author tell us how long that sand bed would last without replacement, and whether enough iron can be removed by agitation and wash to keep the replacement from taking place too often?

Mr. Frank E. Hale: No sand has been replaced in the four operations of the city plants.

The precipitated iron is readily removed by washing. The coating on the sand grains is a close adherent coating; it is not a thick coating, but a thin film.

A Member: If the iron accumulates on top how can you get a catalytic action? This must take place in the sand bed itself, and that would necessitate some iron depositing on the grains where the action takes place. Does it not seem reasonable that if you get a precipitation due to the iron on the sand that you get iron deposited in the sand rather than on top of it?

Mr. Frank E. Hale: Experience does not show that it accumulates to a troublesome extent. Catalytic action refers to the giving up and taking up of oxygen by the iron repeatedly and may take place on top of the sand bed as well as in it.

Mr. Robert E. Milligan: In an experience of over twenty years, covering actual operation of iron removal plants, ranging from Massachusetts to Iowa, Illinois, Long Island, New Jersey and Maine, the necessity of the precipitation of iron with an alkali, preferably lime, has been conclusively shown. Even where this was done there was a creeping action throughout the sand bed which finally resulted in an increased amount of iron in the effluent; and in cases where no alkali was used the increase in the effluent was more quickly had. Upon examination of the filter beds at Freeport, Illinois, and at Quincy, Illinois, it was found that the iron had penetrated throughout the entire mass of the sand bed clear to the strainer system. At Quincy this was equally true of the lime used in conjunction with sulphate of iron to produce a coagulant. At Freeport lime only was used to remove iron in the ground wells forming the source of supply. In all iron removal plants this condition seems to pertain and it becomes necessary to remove the beds.

Mr. Frank E. Hale: How many years did it take?

Mr. Robert E. Milligan: In some cases two years, and in the case of Asbury Park, New Jersey, approximately ten years. In the latter case, however, double filtration is resorted to, using sand and animal charcoal, and the process is greatly assisted by the air lifts used to lift the water to the filters.

Mr. Frank E. Hale: The author's impression from his experience at Rockaway Beach was that the precipitated iron was so fine with the use of alkali that it penetrated the filter beds, but that it tended to a coarser, better precipitate with aeration alone. He had considerable difficulty in inducing Mr. Bettes to stop using soda. But the experience this year has shown that fully as good results are obtained without the use of coagulants.

Mr. A. J. Provost, Jr. (by letter): The paper presented by Mr. Hale brings out some of the most interesting of the problems related to deferrization of ground waters.

The two municipal plants referred to at Baisley's Pond and Springfield Pond of the Brooklyn water supply are good examples of the simplicity of iron removal from certain shallow subsurface waters, such as occur frequently on Long Island, New Jersey, etc. These installations also illustrate how an apparatus may clearly fail in the purpose for which it is designed, and still be of great service for some quite different purpose. Space may perhaps be permitted to briefly state the rather unique history of these two filter plants.

Prior to 1902 a portion of the Brooklyn supply was taken from surface waters stored in Baisley's Pond and Springfield Pond, both of which were subject to important pollutions which the city was unable to control.

A contract was entered into in 1901 for the installation of rapid sand filters from the contractors' designs for the purification of these supplies under guarantee as to sanitary efficiency. Tests conducted in 1901 and 1902 were unsatisfactory, and it was not until 1904 that the filters were accepted by the city, after material modifications had been made in the construction and operating features. In 1905 the Baisley's plant filtered on the average 4.25 m.g.d., at a cost of $6.53 per million gallons, and the Springfield plant filtered on the average 2 m.g.d. at a cost of $9.58 per million gallons. Both plants then gave a satisfactory degree of purification, although there were some operating difficulties.

By 1908 the average daily yield at Baisley's was only 2.8 m.g.d. at a cost of $12.98 per million gallons, and at Springfield only 0.9 m.g.d. at a cost of $13.24 per million gallons. The removal of bacteria in both plants during that year averaged about 98 per cent, and Coli were present in about 3.5 per cent of 10 cc. inoculations of the filtered water.

In 1909 the plants were reported in dangerous condition, due to lax supervision, and they were subsequently abandoned in favor of shallow wells which, it was expected, would collect the pond waters after sufficient natural filtration through the soil. These waters when so collected were found to contain prohibitive amounts of iron. The old filter plants were then changed somewhat and used for the removal of excess iron, with the very satisfactory results given in the author's paper.

The author has also given us an excellent example of one of the more difficult phases of deferrization. The various steps undertaken in working out and solving the Rockaway Park problem are interesting and instructive. Here we have a water with no materially greater iron content, but with entirely different characteristics. Doubtless the carbonic acid content of this water is one of the important determining elements, although it is possible manganese is present and not determined and reported. The writer has had some recent experience with iron removal from water taken from wells about 550 feet deep at Jamaica, Long Island. The iron is present in amounts averaging about 2.5 parts per million, associated with manganese about two-third parts per million, and carbonic acid about 25 parts per million.

Although the water is raised from the well by air lift, and is in contact with air in the well for a period of about 2½ minutes before its discharge, and is further aerated by passing over a wier about 47 feet long, equivalent to about 10 gallons per minute per linear foot of wier as it enters the filters, it was impossible to remove a substantial proportion of the iron content by filtration, except by relatively slow rates after a considerable period of sedimentation, and it was impossible to reduce the iron and manganese to a satisfactory degree by means of rapid filtration except after neutralization of the carbonic acid by coagulation with lime for a substantial period. Analyses of the water, extending over an extended period, indicate a soft water with general absence of organic impurities and high in iron, manganese and CO_2. The normal iron fluctuates, but averages about 2.50 parts per million, as shown by twenty examinations during a period of four years, with a maximum of about 4 parts.

The apparatus used for iron removal with respect to which the following tests are reported, was designed by the writer, and consists of a filter 15 feet interior diameter, containing 28 inches Cape May sand, having an effective size of 0.43 mm., and a uniformity coefficient of 1.5.

The floor system is similar in principle to the ridge block strainer type, but is believed to embody some novel features. Wash water is used at moderate rates in combination with air. A balanced butterfly valve with float control regulates the rate of filtration. The sedimentation tank has a capacity of about 17,000 gallons, and is provided with baffles. Water from the well is discharged into the sedimentation tank head box where it is dosed with the coagulant solutions.

The following table gives the essential data relating to the conditions of the tests and the results secured:

	RATE OF FILTRATION—MILLION GALLONS PER ACRE PER DAY	COAGULATION PERIOD	COAGULANTS—GRAINS PER GALLON			RAW WATER—PARTS PER MILLION				FILTERED WATER—PARTS PER MILLION				IRON REDUCED
			Alum	Soda Ash	Lime	Alkalinity	Hardness		Iron	Alkalinity	Hardness		Iron	
							Temp.	Perm.			Temp.	Perm.		
		minutes												*per cent*
July 16–29, 1915.....	169	30	0.5	0.5					1.8				0.9	50
August 5, 1915.....	125	45	0.5	0.5					0.7				0.5	30
	50	120	0.5	0.5									0.2	70
August 11, 1915....	169	30			1	30.2	22.5	15.0	3.0	37.5	23.8	17.3	0.4	86
	169	30			2					45.9	67.4	21.2	0.25	92
	125	45			1						35.1	19.9	0.3	90
	125	45			2						28.7	23.8	0.05	98
September 20, 1915...	169	30			1.5				2.20				0.2	91

The conclusions drawn from these tests were:

That it is not feasible to remove a sufficient amount of the iron, manganese and CO_2 content by filtration at high rates after coagulation with alum and soda ash in reasonable quantities without a prohibitive period for coagulation and oxidation.

That it is feasible to absorb the CO_2 and to remove substantially all the iron and manganese by filtration at high rates (125 to 169 million gallons per acre day) if preceded by coagulation with lime at the rate of 1 to 1.5 grains per gallon, and a period of coagulation and oxidation of from one-half to three-quarters of an hour without increasing the hardness of the water beyond that of other important local supplies which are considered soft.

The author is to be complimented for having made available the results of the experiments at Rockaway Park in the clear manner in which they are presented. It is quite evident that with brief sedimentation rapid filtration was unsatisfactory, even when large amounts of soda ash were used to neutralize the CO_2, and that with greatly increased sedimentation and elaborate means for aeration, satisfactory results were accomplished without the use of coagulant. It would have been of added interest if, after the installation of the large sedimentation tank, relatively small amounts of lime had been tried in order to determine whether the expense of aeration rendered it an economical substitute.

The author is quite correct in characterizing the use of native sand as an unwise procedure. The writer has examined the characteristics of a large number of sands from more than twenty different localities on Long Island, and has found none which could be successfully used for rapid filters except after a prohibitive amount of washing and screening. It is better to pay a higher price and secure an article that will give satisfactory service.

The author's paper emphasizes the importance of careful scientific investigation preliminary to the design and construction of all permanent iron removal plants.

Not all of these problems are alike or even similar, and it is quite probable that insufficient attention has been given in many instances to the important effect which associated minerals, such as lime, manganese and CO_2 have in the interference with successful iron removal.

Mr. Frank E. Hale: In the plant at Jamaica, Long Island, Mr. Provost does not appear to have tried splashing-aeration in place of the use of chemicals. As stated in the paper, the chief difficulty is to get rid of carbonic acid. The extra head pumped for aeration at Rockaway Park is less than 10 feet. With an economical pumping plant this extra head would not cost more than 55 cents per million gallons, which would mean at Rockaway Park about 33 cents a day. If lime were used, probably about 3 grains per gallon would be needed, which, alone, would cost $1 a day. Consequently, it is cheaper to pump the extra head than to purchase lime, to say nothing of the trouble and labor in applying the lime.

The presence of manganese would not have any bearing upon any questions of difficulty in removing iron, since in alkaline solution manganese readily absorbs oxygen and passes to hydrated dioxide. In fact this reaction is the basis of the Winkler method for determining dissolved oxygen in water. Furthermore, manganese is removed from water supplies in Europe by similar oxidation on beds of manganese permutite.